AS Physics CIE

YOUR NOTES

10. D.C. Circuits

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- 10.2.1 Potential Dividers
- 10.2.2 Potential Divider Components

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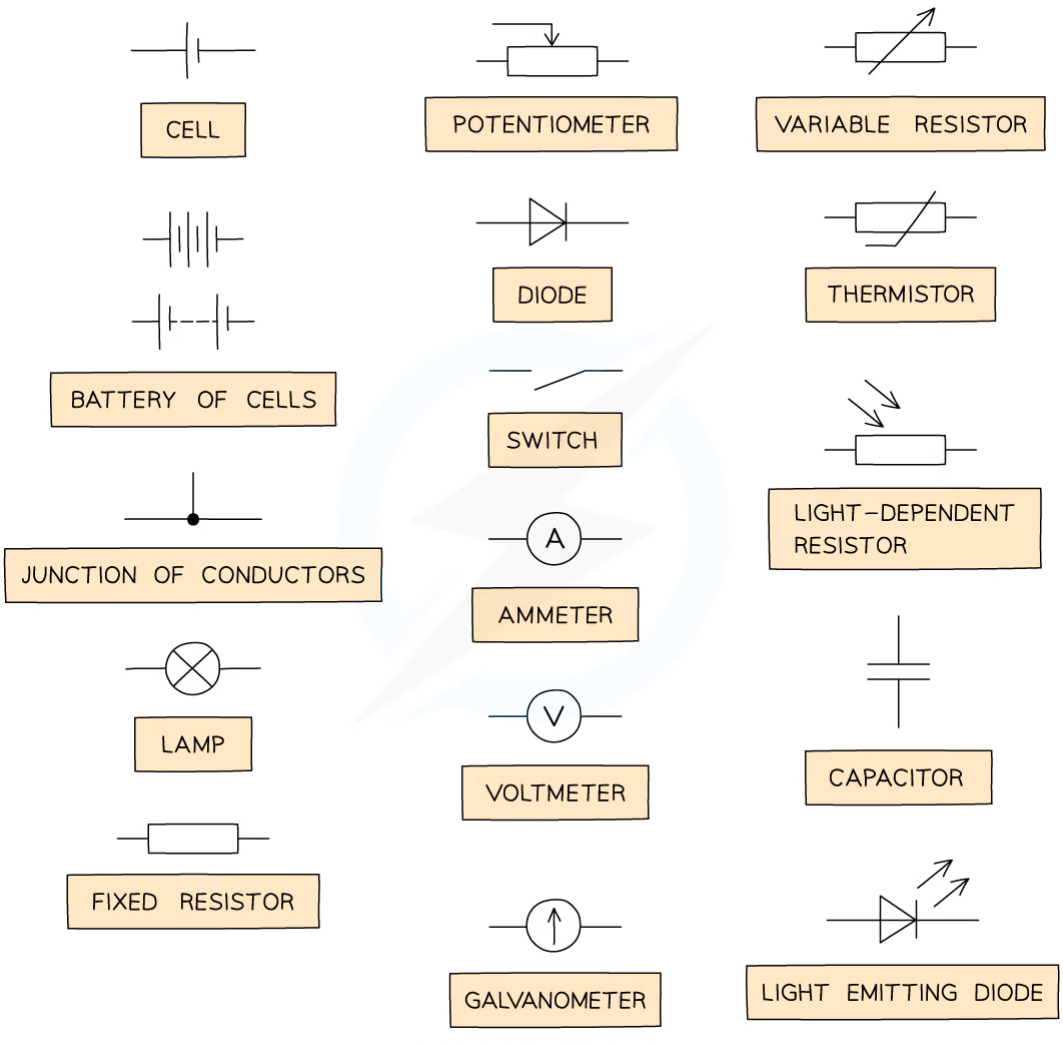
10.1 DC: Practical Circuits & Kirchhoff's Laws

10.1.1 Circuit Symbols

Circuit Symbols

- The diagrams below show the various circuit symbols that could be used in circuit diagrams. You will be expected to recognise and draw all of these
- The most common symbols are as follows:



Common circuit symbols

- The function of the most common components are:
  - **Switch:** Turn the circuit on (closed), or off (open)
  - **Fixed resistor:** A resistor limits the flow of current. A fixed resistor has a resistance it cannot change

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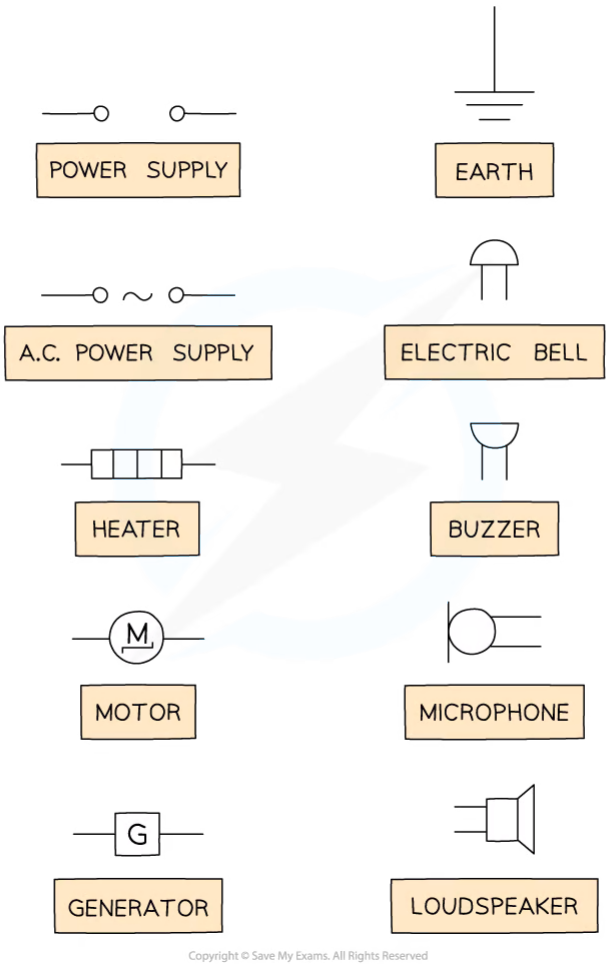
- **Variable resistor:** A resistor with a slider that can be used to change its resistance. Used often in dimmer switches and volume controls
- **Thermistor:** The resistance of a thermistor depends on its temperature. As its temperature increases, its resistance decreases and vice versa
- **Light-dependent resistor (LDR):** The resistance of an LDR depends on the light intensity. As the light intensity increases, its resistance decreases and vice versa
- **Diode:** A diode allows current to flow in one direction only. They are used to convert AC to DC current
- **Light-emitting diode (LED):** This is equivalent to a diode and emits light when a current passes through it. These are used for aviation lighting and displays (TVs, road signs)
- **Ammeter:** Used to measure the current in a circuit. Connected in series with other component
- **Voltmeter:** Use to measure the potential difference of an electrical component. Connected in parallel with component

- The more uncommon, yet relevant symbols, are as follows:



Other circuit symbols

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Exam Tip

You must memorise all of these circuit symbols for the exam. To make it easier for you, we have separated the symbols into the most common symbols, and the symbols that don't come up as often, however, you should be aware of all of them!

YOUR NOTES

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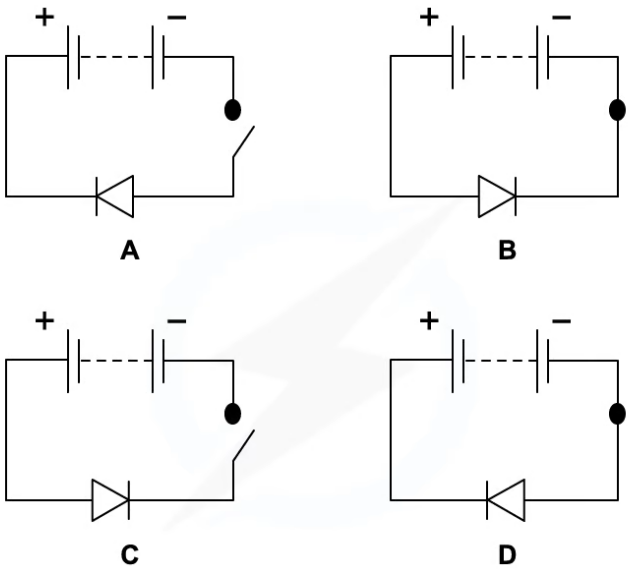
Interpreting Circuit Diagrams

YOUR NOTES

- Being able to draw and interpret circuit diagrams using circuit symbols is an essential skill in Electronics

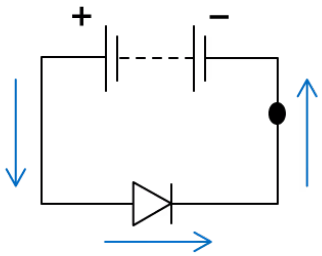
Worked Example

Which circuit diagram correctly represents a circuit with current flowing through?



ANSWER: B

THIS IS SEEN IN CIRCUIT B



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- For a circuit to be connected, the switch must be closed
  - This is either circuit **B** or **D**
- The other circuit symbol is a diode
  - Diodes only allow current to flow in one direction
- Since current flow is from positive to negative, a forward-biased diode must point in this direction in order for the current to flow
  - This is seen in circuit **B**

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Electromotive Force

- When charge passes through a power supply such as a battery, it **gains** electrical energy
- The **electromotive force (e.m.f)** is the amount of **chemical** energy converted to **electrical** energy per **coulomb** of charge **(C)** when charge passes through a power supply
- e.m.f is measured in **Volts (V)**

$$\text{E.M.F.} = \frac{\text{ENERGY TRANSFORMED FROM OTHER FORMS TO ELECTRICAL}}{\text{CHARGE}}$$

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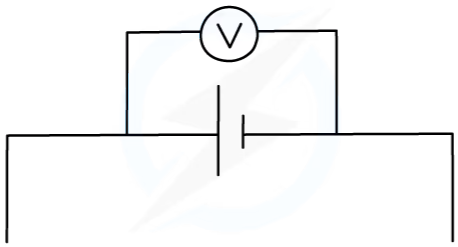
Definition of e.m.f with regards to energy transfer

- e.m.f is also the potential difference across the cell when no current is flowing
- e.m.f can be measured by connecting a high-resistance voltmeter around the terminals of the cell in an open circuit



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e.m.f is measured using a voltmeter connected in parallel with the cell

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EMF & Potential Difference

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- The difference between **potential difference** and **e.m.f** is the type of energy transfer per unit charge

$$\text{P.D.} = \frac{\text{ENERGY TRANSFORMED FROM ELECTRICAL TO OTHER FORMS}}{\text{CHARGE}}$$

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Definition of potential difference with regards to energy transfer

- When charge passes through a resistor, for example, its electrical energy is converted to heat in the resistor
  - The resistor therefore has a **potential difference** across it
- Potential difference describes the loss of energy from charges; ie. when **electrical energy** is **transferred** to other forms of energy in a component
- e.m.f. describes the **transfer of energy** from the **power supply** to **electrical charges** within the circuit

Exam Tip

Although voltage and potential difference are the same thing, make sure not to confuse them with e.m.f, which is slightly different!

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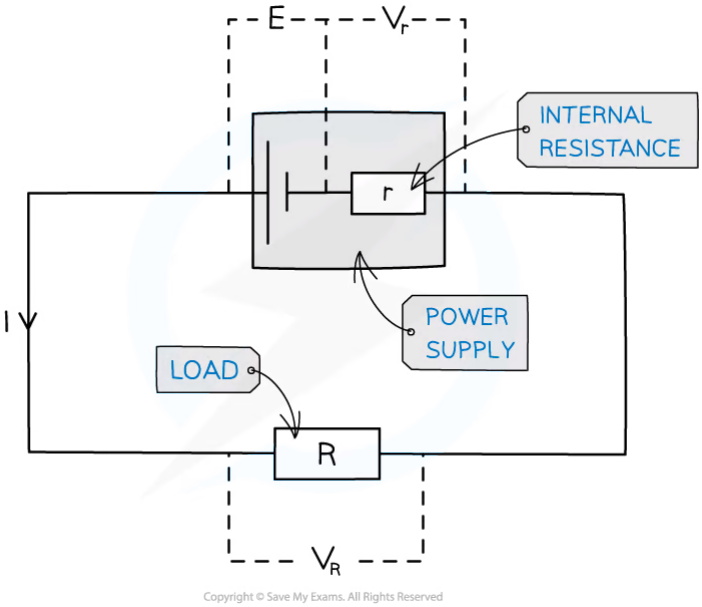
Internal Resistance

- All power supplies have some resistance between their terminals
  - This is called **internal resistance** (*r*)
- This internal resistance causes the charge circulating to dissipate some electrical energy from the power supply itself
  - This is why the cell becomes warm after a period of time
- The internal resistance therefore causes **loss of voltage** or energy loss in a power supply
- A cell can be thought of as a source of e.m.f with an internal resistance connected in series. This is shown in the circuit diagram below:



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Circuit showing the e.m.f and internal resistance of a power supply

- V_R is the **terminal potential difference**
  - This is the voltage available in the circuit itself
  - **Terminal p.d** = $I \times R$ (Ohm's law)
- When a load resistor is connected, current flows through the cell and a potential difference develops across the internal resistance. This voltage is not available to the rest of the circuit so is called the 'lost volts'
- V_r is the **lost volts**
  - This is the voltage lost in the cell due to internal resistance, so, from conservation of energy:
  - Lost volts = e.m.f − terminal p.d

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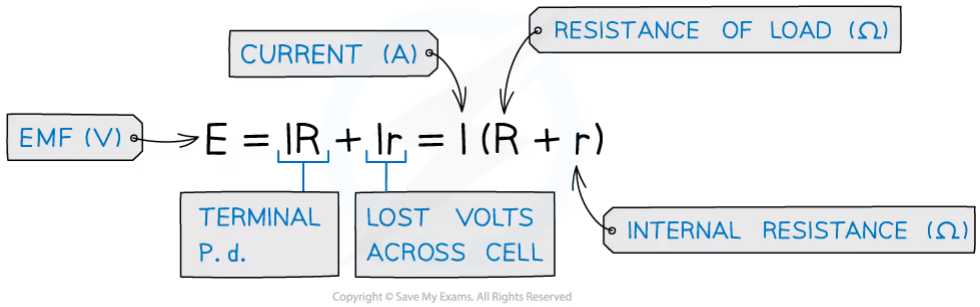
YOUR NOTES

- **Lost volts** = $I \times r$ (Ohm's law)

- The e.m.f is the sum of these potential differences, giving the equation below


CURRENT (A)
RESISTANCE OF LOAD (Ω)
EMF (V)
E = IR + Ir = I (R + r)
TERMINAL P. d.
LOST VOLTS ACROSS CELL
INTERNAL RESISTANCE (Ω)
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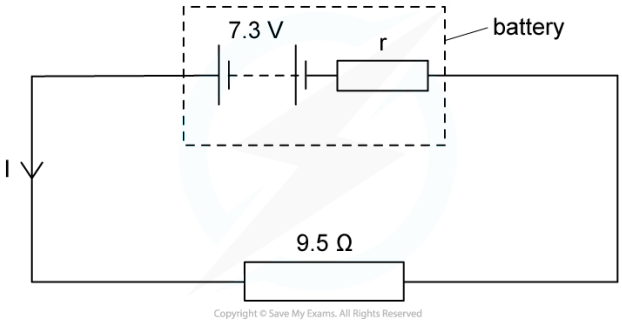
e.m.f equation

- e.m.f is therefore the total, or maximum, voltage available to the circuit

Worked Example

A battery of e.m.f 7.3 V and internal resistance r of 0.3 Ω is connected in series with a resistor of resistance 9.5 Ω.



Determine:

a) The current in the circuit

b) Lost volts from the battery

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YOUR NOTES

a.)

STEP 1 USING THE e.m.f EQUATION TO DETERMINE THE CURRENT I

$$E = I(R + r)$$

STEP 2 REARRANGE FOR I

$$I = \frac{E}{(R + r)}$$

STEP 3 SUBSTITUTE IN THE VALUES

$$I = \frac{7.3}{(9.5 + 0.3)} = 0.745... = 0.7\ A \quad (2\ s.f.)$$

b.)

STEP 1 THE LOST VOLTS IS THE VOLTAGE LOST DUE TO INTERNAL RESISTANCE

$$LOST\ VOLTS = I \times r$$

STEP 2 SUBSTITUTE IN THE VALUES

$$LOST\ VOLTS = 0.7 \times 0.3 = 0.21 = 0.2 \quad (2\ s.f.)$$

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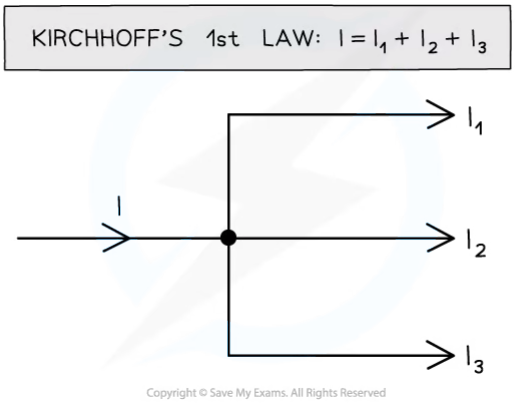
Kirchhoff's First Law

- Kirchhoff's first law states that:
  - **The sum of the currents entering a junction always equal the sum of the currents out of the junction**
- This is a consequence of conservation of **charge** – current shouldn't decrease or increase in a circuit when it splits
- In a circuit:
  - A **junction** is a point where at least three circuit paths meet
  - A **branch** is a path connecting two junctions
- If a circuit splits into two branches, then the current before the circuit splits should be equal to the current after it has split
- In the circuit below, $I = I_1 + I_2 + I_3$, where I represents the current in the circuit before it branches, and I_1, I_2 and I_3 represent the current in the respective three branches:



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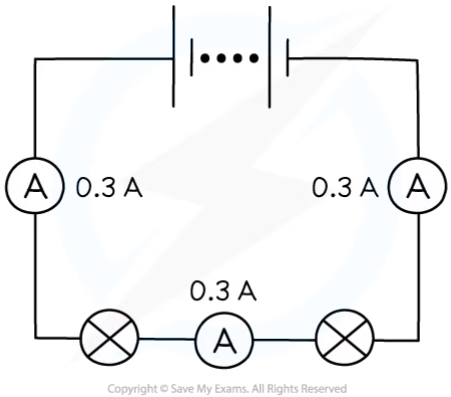
The current I into the junction is equal to the sum of the currents out of the junction

- The charge is conserved on both sides of the junction
- In a **series** circuit, the current is the same at any point



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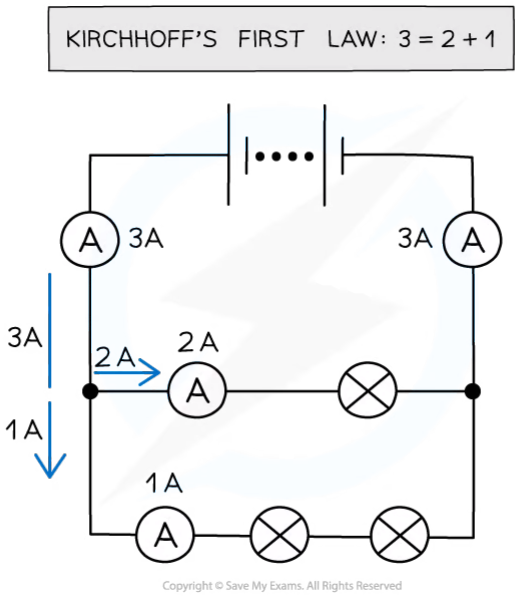
The current is the same at all points in a series circuit

- In a **parallel** circuit, the current divides at the junctions and each branch has a different value. Kirchhoff's first law applies at each junction



The current divides at each junction in a parallel circuit

Exam Tip

Junctions only appear in parallel circuits and as circuits become more complex, it can be confusing as to which currents are into the junction and which are out.Drawing arrows on the diagram for the current flow (making sure it's from positive to negative) at each junction like in the worked example will help with this.

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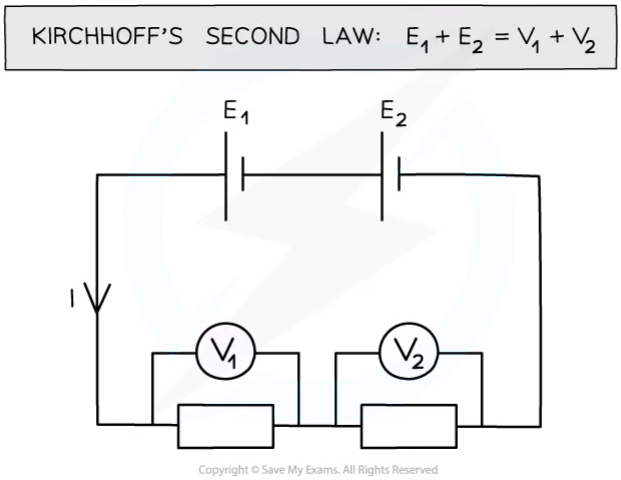
Kirchhoff's Second Law

- Kirchhoff's second law states that:
  - **The sum of the e.m.f's in a closed circuit equals the sum of the potential differences**
- This is a consequence of conservation of **energy**
- Below is a circuit explaining Kirchhoff's second law with the sum of the voltages in the closed series circuit equal to the sum of the e.m.f's:



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The sum of the voltages are equal to the sum of the e.m.f from the batteries

- In a **series** circuit, the voltage is split across all components depending on their resistance
  - The sum of the voltages is equal to the total e.m.f of the power supply
- In a **parallel** circuit, the voltage is the same across each closed loop
  - The sum of the voltages **in each closed circuit loop** is equal to the total e.m.f of the power supply:

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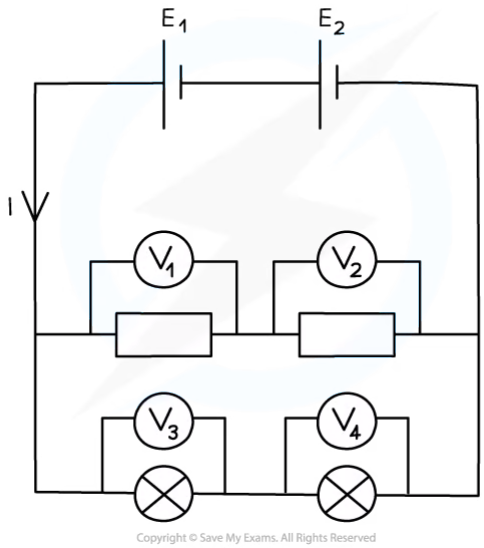
YOUR NOTES

KIRCHHOFF'S SECOND LAW: $E_1 + E_2 = V_1 + V_2 = V_3 + V_4$



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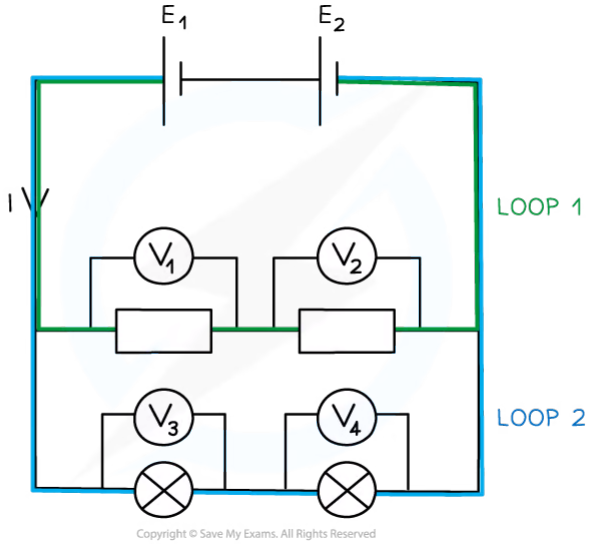
- A closed circuit loop acts as its own independent series circuit and each one separates at a junction. A parallel circuit is made up of two or more of these loops



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Each circuit loops acts as a separate, independent series circuit

- This makes parallel circuits incredibly useful for home wiring systems: a single power source supplies all lights and appliances with the same voltage
- If one light breaks, voltage and current can still flow through for the rest of the lights and appliances

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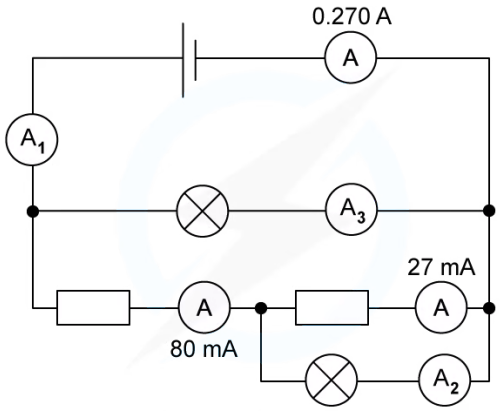
YOUR NOTES

Solving Problems with Kirchhoff's Laws

- Kirchhoff's laws can be used to solve simple circuit problems

Worked Example

For the circuit below, state the readings of ammeters A_1, A_2 and A_3.



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STEP 1

AMMETER A_1

0.270 A AND A_1 ARE CONNECTED IN SERIES. THE CURRENT ENTERING THE CELL EQUALS THE CURRENT LEAVING IT

A_1 IS ALSO 0.270 A

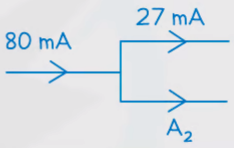
STEP 2

AMMETER A_2

FROM KIRCHHOFF'S FIRST LAW, THE TOTAL CURRENT INTO THE JUNCTION MUST EQUAL THE TOTAL CURRENT OUT OF IT.

$80\ mA = 27\ mA + A_2$

$A_2 = 80 - 27 = 53\ mA$



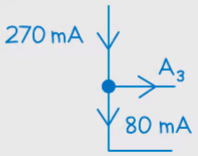
STEP 3

AMMETER A_3

KIRCHHOFF'S FIRST LAW AT A DIFFERENT JUNCTION

$270\ mA = A_3 + 80\ mA$

$A_3 = 270 - 80 = 190\ mA$



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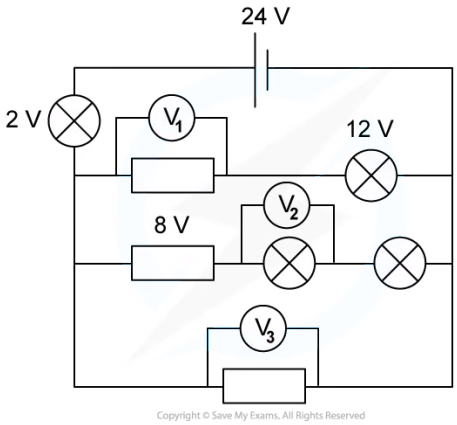
Worked Example

Kirchhoff's Second Law Worked Example

For the circuit below, state the readings of the voltmeters V_1, V_2 and V_3.

All the lamps and resistors have the same resistance.



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YOUR NOTES

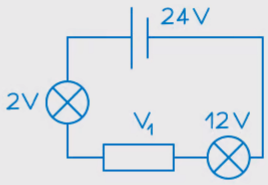
STEP 1

VOLTMETER V_1

KIRCHHOFF'S SECOND LAW STATES THAT THE SUM OF THE THREE COMPONENTS IS EQUAL TO THE e.m.f OF THE SUPPLY

$2V + V_1 + 12V = 24V$

$V_1 = 24 - 12 - 2 = 10V$



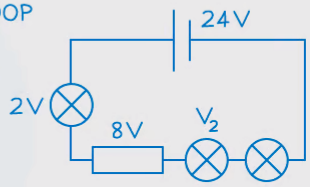
STEP 2

VOLTMETER V_2

KIRCHHOFF'S SECOND LAW IN THIS LOOP

$2V + 8V + V$ OF BOTH LAMPS $= 24V$

V BOTH LAMPS $= 24 - 8 - 2 = 14V$



SINCE BOTH LAMPS HAVE THE SAME RESISTANCE R AND THE CURRENT I THROUGH THEM BOTH IS THE SAME, THEY SHARE THE VOLTAGE LEFT EQUALLY

$V_2 = \frac{14}{2} = 7V$

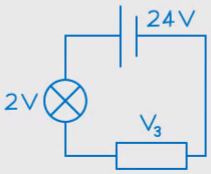
STEP 3

VOLTMETER V_3

KIRCHHOFF'S SECOND LAW IN THIS LOOP

$2V + V_3 = 24V$

$V_3 = 24 - 2 = 22V$



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YOUR NOTES

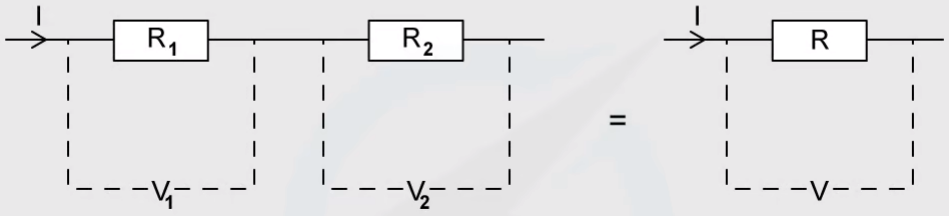
Deriving the Equation for Resistors in Series

- In a series circuit, the combined resistance of two or more resistors is the sum of the individual resistances
- In a series circuit:
  - The current is the same through all resistors
  - The potential difference is split between all the resistors
- The equation for combined resistors in series is derived using Kirchhoff's laws:

Derivation for resistors in series

CONSIDER TWO RESISTORS R_1 AND R_2 CONNECTED IN SERIES.
A SINGLE RESISTOR R IS EQUIVALENT TO THEM.

FROM KIRCHHOFF'S FIRST LAW: THE CURRENT I THROUGH EACH RESISTOR IS THE SAME SINCE THEY'RE CONNECTED IN SERIES (NO JUNCTIONS)



FROM KIRCHHOFF'S SECOND LAW: THE TOTAL p.d OF BOTH RESISTORS IN A CLOSED CIRCUIT LOOP MUST EQUAL THE SUM OF THE p.ds (THE p.d ACROSS THE SINGLE RESISTOR)

$$V = V_1 + V_2$$

FROM OHM'S LAW, POTENTIAL DIFFERENCE IS GIVEN BY THE PRODUCT OF CURRENT AND RESISTANCE

$$IR = IR_1 + IR_2$$

SINCE CURRENT I IS THE SAME FOR ALL RESISTORS, DIVIDING BY I

$$R = R_1 + R_2$$

THIS EQUATION CAN BE EXTENDED SO THE EQUIVALENT RESISTOR R OF SEVERAL RESISTORS CONNECTED IN SERIES IS GIVEN BY

$$R = R_1 + R_2 + R_3 + R_4 \ldots$$

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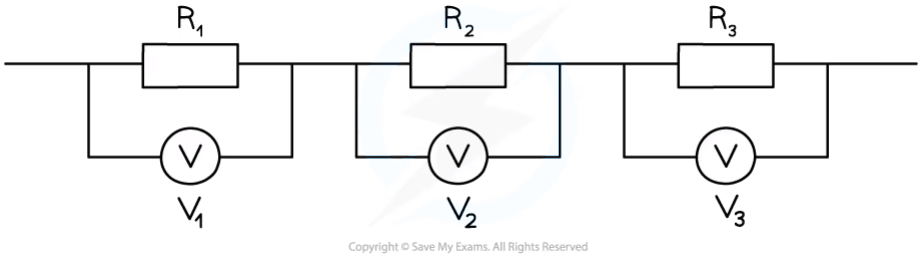
Resistors in Series

YOUR NOTES

- When two or more components are connected in series:
  - **The combined resistance of the components is equal to the sum of individual resistances**



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Resistors connected in series

$$\text{COMBINED RESISTANCE IN SERIES} \quad R = R_1 + R_2 + R_3 \ldots$$

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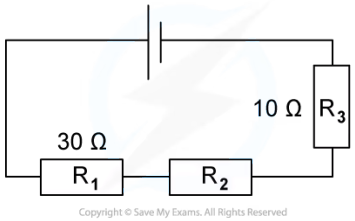
Combined resistance of two or more resistors in series equation

Worked Example

The combined resistance *R* in the following series circuit is 60 Ω.What is the resistance value of R_2?



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A. 100 Ω **B.** 30 Ω **C.** 20 Ω **D.** 40 Ω

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ANSWER: C

YOUR NOTES

STEP 1

EQUATION FOR COMBINED RESISTANCE IN SERIES

$$R = R_1 + R_2 + R_3$$

STEP 2

SUBSTITUTE IN VALUES FOR TOTAL RESISTANCE R AND THE OTHER RESISTORS

$$60\Omega = 30\Omega + R_2 + 10\Omega$$

STEP 3

REARRANGE FOR R_2

$$R_2 = 60\Omega - 30\Omega - 10\Omega$$

$$R_2 = 20\Omega$$

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YOUR NOTES

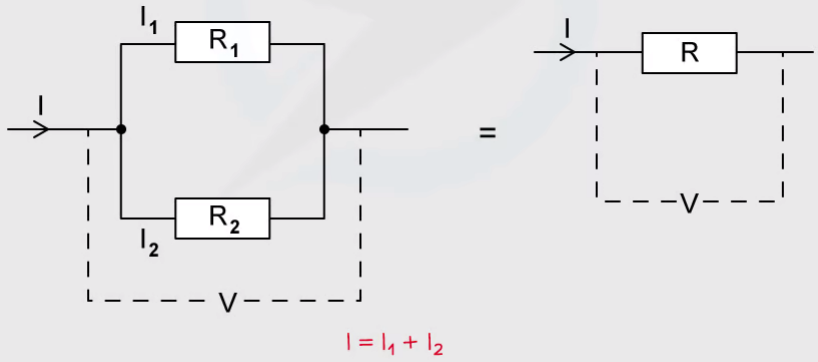
Deriving the Equation for Resistors in Parallel

- In a parallel circuit, the reciprocal of the combined resistance of two or more resistors is the sum of the reciprocal of the individual resistances
- In a parallel circuit:
  - The current is the split at the junction (and therefore between resistors)
  - The potential difference is the same through all resistors
- The equation for combined resistors in parallel is derived using Kirchhoff's laws:

Derivation for resistors in parallel

CONSIDER TWO RESISTORS R_1 AND R_2 CONNECTED IN PARALLEL. A SINGLE RESISTOR R IS EQUIVALENT TO THEM.

FROM KIRCHHOFF'S SECOND LAW: THE CURRENT THROUGH EACH RESISTOR WILL BE DIFFERENT DUE TO THE CURRENT SPLITTING AT THE JUNCTION. THE CURRENT THROUGH THE EQUIVALENT RESISTOR R WILL BE THE TOTAL CURRENT I



$I = I_1 + I_2$

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FROM KIRCHHOFF'S SECOND LAW, THE P.D ACROSS EACH RESISTOR IN DIFFERENT BRANCHES IS THE SAME.
THE RESISTOR R WILL HAVE THAT SAME p.d ACROSS IT TOO

$$V = V_1 = V_2$$

REARRANGING OHM'S LAW $V = IR$ FOR CURRENT I

$$I = \frac{V}{R}$$

$$\frac{V}{R} = \frac{V}{R_1} + \frac{V}{R_2}$$

SINCE POTENTIAL DIFFERENCE V IS THE SAME FOR ALL RESISTORS, DIVIDING BY V

$$\frac{I}{R} = \frac{I}{R_1} + \frac{I}{R_2}$$

THIS EQUATION CAN BE EXTENDED SO THE EQUIVALENT RESISTOR R OF SEVERAL RESISTORS CONNECTED IN PARALLEL IS GIVEN BY

$$\frac{I}{R} = \frac{I}{R_1} + \frac{I}{R_2} + \frac{I}{R_3} \cdots$$

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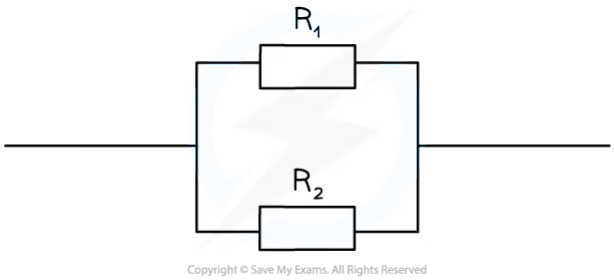
YOUR NOTES

Resistors in Parallel

- When two or component are connected in parallel:
  - **The reciprocal of the combined resistance is the sum of the reciprocals of the individual resistances**



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Resistors connected in parallel

COMBINED RESISTANCE IN PARALLEL

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \ldots$$

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Combined resistance of two or more resistors in parallel equation

- This means the combined resistance decreases and is less than the resistance of any of the individual components
- For example, If two resistors of equal resistance are connected in parallel, then the combined resistance will halve

Maths tip

- The reciprocal of a value is 1 / value
- For example, the reciprocal of a whole number such as 2 equals ½
  - The reciprocal of ½ is 2
- If the number is already a fraction, the numerator and denominator are 'flipped' round

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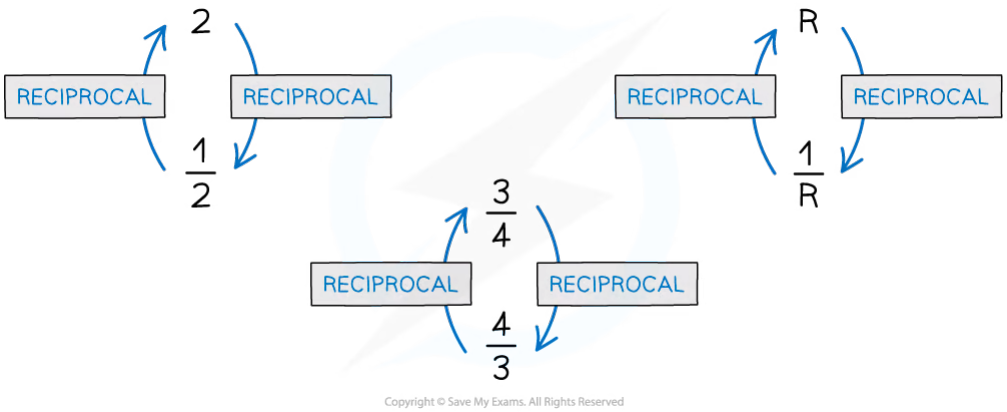
YOUR NOTES

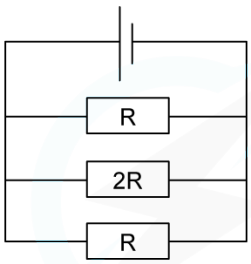


The reciprocal of a number is 1 ÷ number

- In the case for the resistance R, this becomes 1/R. To get the value of R from 1/R, you must do 1 ÷ your answer
- You can also use the reciprocal button on your calculator (labelled either x^{-1} or 1/x, depending on your calculator

Worked Example

The circuit below shows 3 resistors connected in parallel.



Which value gives the combined resistance of all the resistors in this circuit?

A. $\frac{5R}{2}$ **B.** $\frac{2}{5R}$ **C.** $\frac{5}{2R}$ **D.** $\frac{2R}{5}$

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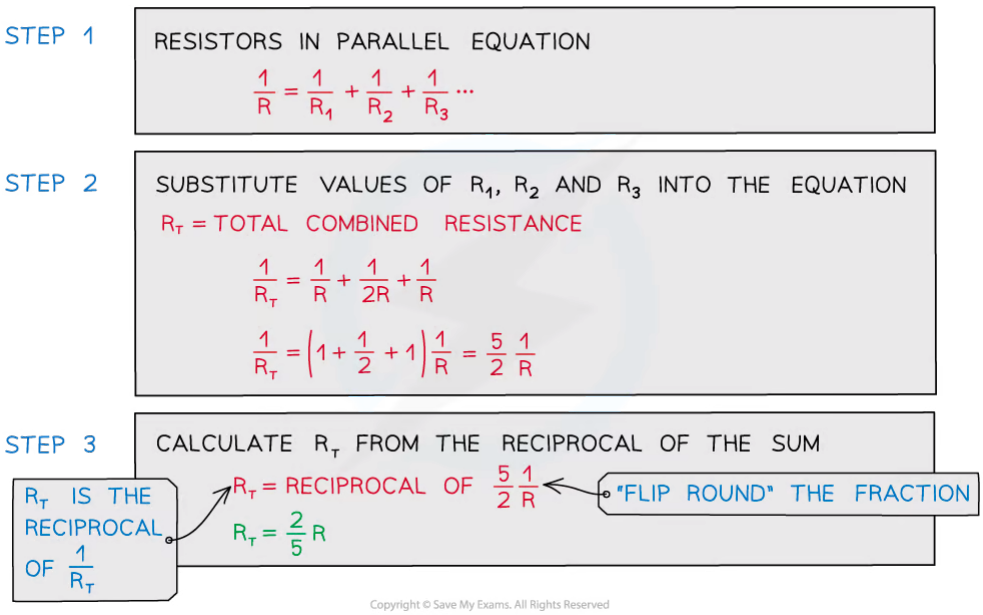
ANSWER: D


STEP 1
RESISTORS IN PARALLEL EQUATION
$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \ldots$
STEP 2
SUBSTITUTE VALUES OF R_1, R_2 AND R_3 INTO THE EQUATION
R_T = TOTAL COMBINED RESISTANCE
$\frac{1}{R_T} = \frac{1}{R} + \frac{1}{2R} + \frac{1}{R}$
$\frac{1}{R_T} = \left(1 + \frac{1}{2} + 1\right)\frac{1}{R} = \frac{5}{2}\frac{1}{R}$
STEP 3
CALCULATE R_T FROM THE RECIPROCAL OF THE SUM
R_T IS THE RECIPROCAL OF $\frac{1}{R_T}$
R_T = RECIPROCAL OF $\frac{5}{2}\frac{1}{R}$
"FLIP ROUND" THE FRACTION
$R_T = \frac{2}{5}R$

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Exam Tip

The most common mistake is to forget to find $1/R_T$ and not R_T. Remember to do 1 / answer to get this value

YOUR NOTES

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YOUR NOTES

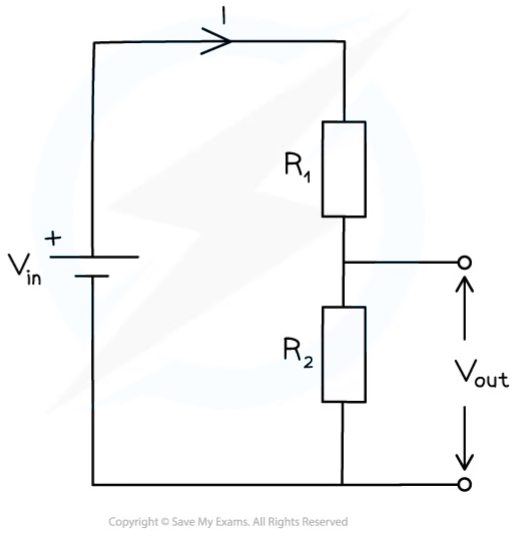
10.2 DC: Potential Dividers

10.2.1 Potential Dividers

Potential Divider Circuit

- When two resistors are connected in series, through Kirchhoff's Second Law, the potential difference across the power source is divided between them
- Potential dividers are circuits which produce an output voltage as a **fraction** of its input voltage
- Potential dividers have two main purposes:
  - To provide a variable potential difference
  - To enable a specific potential difference to be chosen
  - To split the potential difference of a power source between two or more components
- Potential dividers are used widely in volume controls and sensory circuits using LDRs and thermistors
- Potential divider circuits are based on the ratio of voltage between components. This is equal to the ratio of the resistances of the resistors in the diagram below, giving the following equation:

$$\text{POTENTIAL DIVIDER EQUATION: } V_{out} = \frac{R_2}{R_1 + R_2} V_{in}$$



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Potential divider diagram and equation

- The input voltage V_{in} is applied to the top and bottom of the series resistors
- The output voltage V_{out} is measured from the centre to the bottom of resistor R_2
- The potential difference V across each resistor depends upon its resistance R:

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YOUR NOTES

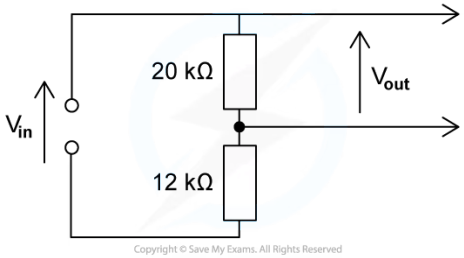
- The resistor with the **largest resistance** will have a **greater potential difference** than the other one from $V = IR$
- If the resistance of one of the resistors is increased, it will get a greater share of the potential difference, whilst the other resistor will get a smaller share

- In potential divider circuits, the p.d across a component is proportional to its resistance from $V = IR$

Worked Example

The circuit is designed to light up a lamp when the input voltage exceed a preset value.

It does this by comparing V_{out} with a fixed reference voltage of 5.3 V.



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V_{out} is equal to 5.3

Calculate the input voltage V_{in}.

STEP 1

POTENTIAL DIVDER EQUATION

$$V_{out} = \left(\frac{R_1}{R_1 + R_2}\right) V_{in}$$

STEP 2

REARRANGE FOR INPUT VOLTAGE V_{in}

$$V_{in} = V_{out} \div \left(\frac{R_1}{R_1 + R_2}\right) = V_{out} \times \left(\frac{R_1 + R_2}{R_1}\right)$$

STEP 3

SUBSTITUTE IN VALUES

$R_1 = 20\ k\Omega$ $R_2 = 12\ k\Omega$ $V_{out} = 5.3\ V$

$$V_{in} = 5.3 \times \left(\frac{12 + 20}{20}\right) = 8.48\ V$$

$V_{in} = 8.5\ V$ (2 s.f.)

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Exam Tip

Always make sure the correct resistance is in the numerator of the potential divider equation. This will be the resistance of the component you want to find the output voltage of.

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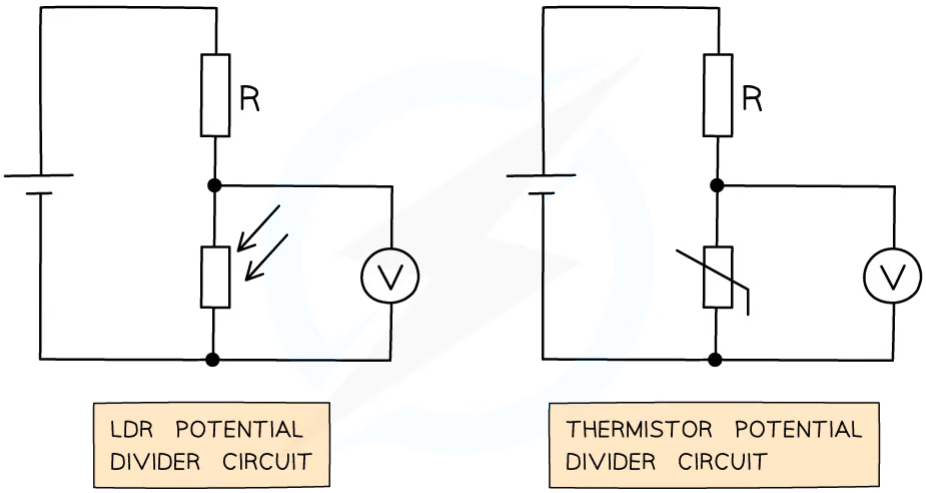
Variable Resistance Components

YOUR NOTES

- Variable and sensory resistors are used in potential dividers to vary the output voltage
  - This could cause an external component to switch on or off e.g. a heater switching off automatically when its surroundings are at room temperature
- Sensory resistors used are **Light Dependent Resistors (LDRs)** and **thermistors**



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LDR and thermistor in a potential divider circuit with a fixed resistor R

- The voltmeter in both circuits is measuring V_{out}
- Recall that the resistance of an LDR varies with light intensity
  - The higher the light intensity, the lower the resistance and vice versa
- An LDR circuit is often used for street and security lights
- The resistance of a thermistor varies with temperature
  - The hotter the thermistor, the lower the resistance and vice versa
- A thermistor circuit is used in fire alarms, ovens and digital thermometers

- From Ohm's law ***V = IR***, the potential difference V_{out} from a resistor in a potential divider circuit is **proportional** to its resistance
  - If an LDR or thermistor's resistance **decreases**, the potential difference through it also **decreases**
  - If an LDR or thermistor's resistance **increases**, the potential difference through it also **increases**
- Since the total p.d of the components must be equal to V_{in}, if the p.d of the sensory resistor **decreases** then the p.d of the other resistor in the circuit must **increase** and vice versa

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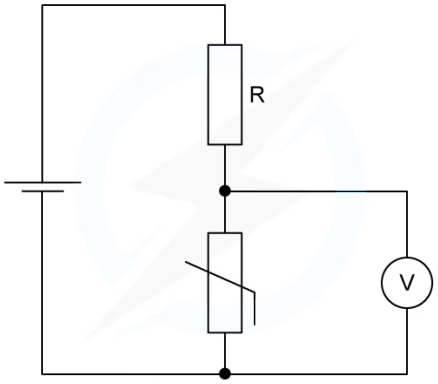
YOUR NOTES

Worked Example

A potential divider consists of a fixed resistor R and a thermistor.



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What happens to the p.d through resistor R and the thermistor when the temperature of the thermistor decreases?

	P.d of Thermistor / V	P.d of Resistor R / V
A	Increases	Increases
B	Decreases	Increases
C	Decreases	Decreases
D	Increases	Decreases

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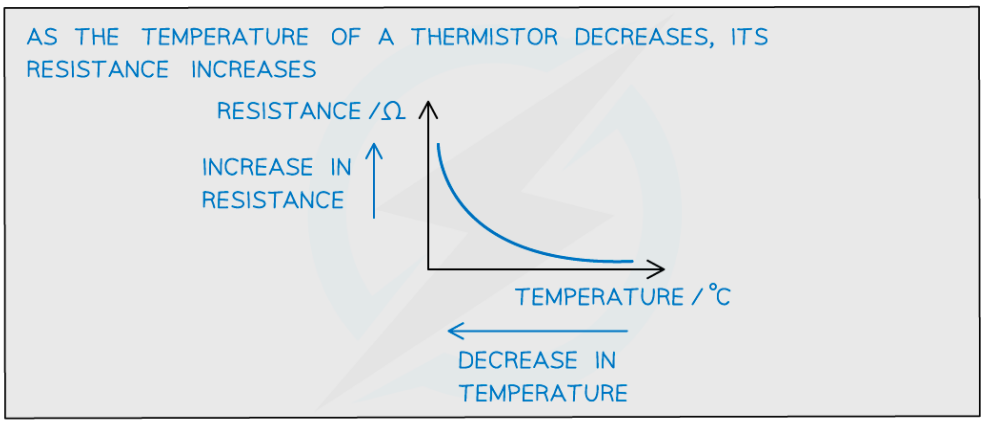
ANSWER: D


AS THE TEMPERATURE OF A THERMISTOR DECREASES, ITS RESISTANCE INCREASES
RESISTANCE / Ω
INCREASE IN RESISTANCE
TEMPERATURE / °C
DECREASE IN TEMPERATURE

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- Due to Ohm's Law (V = IR), both the resistor and thermistor are connected in series and have the same current I
- If resistance *R* increases, the potential difference across the thermistor also **increases**

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- In series, the potential difference is shared equally amongst the components. Their sum equals the e.m.f of the supply (Kirchhoff's second law)
- If the potential difference across the thermistor **increases**, the potential difference across the resistance R must **decreases**, to keep the same overall total e.m.f
- This is row **D**

YOUR NOTES

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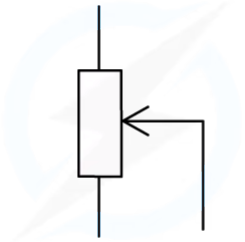
YOUR NOTES

The Potentiometer

- A potentiometer is similar to a variable resistor connected as a potential divider to give a continuously variable output voltage
- It can be used as a means of comparing potential differences in different parts of the circuit
- The circuit symbol is recognised by an arrow next to the resistor



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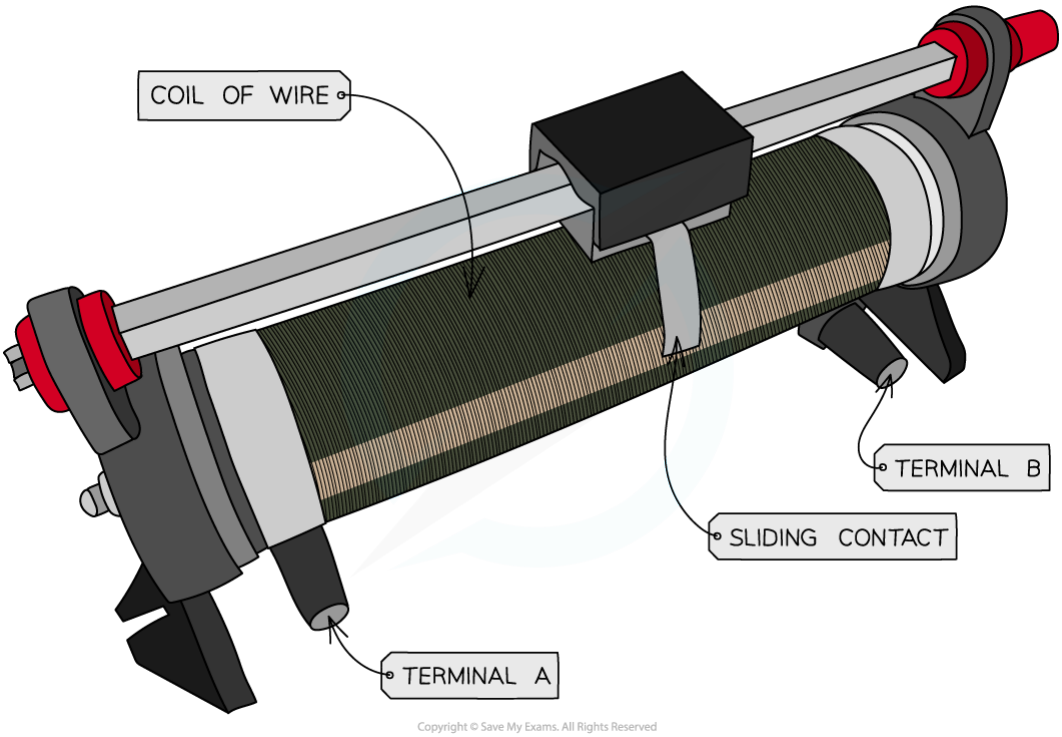
Potentiometer circuit diagram

- A potentiometer is a single component that (in its simplest form) consists of a coil of wire with a sliding contact, midway along it



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A potentiometer is a type of variable resistor

- It is recognised on a circuit diagram with a resistor fitted with a sliding contact

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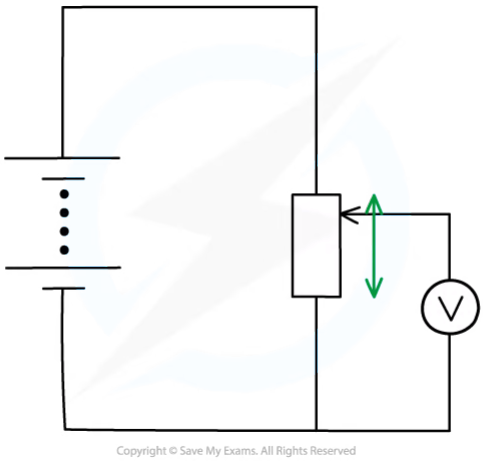
- The sliding contact has the effect of separating the potentiometer into two parts (an upper part and a lower part), both of which have different resistances



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Moving the slider (the arrow in the diagram) changes the resistance (and hence potential difference) of the upper and lower parts of the potentiometer

- If the slider in the above diagram is moved upwards, the resistance of the lower part will increase and so the potential difference across it will also increase
- Therefore, the variable resistor obtains a maximum or minimum value for the output voltage
- If the resistance is 3 Ω:
  - Maximum voltage is when the resistance is 3 Ω
  - Minimum voltage is when the resistance is 0 Ω

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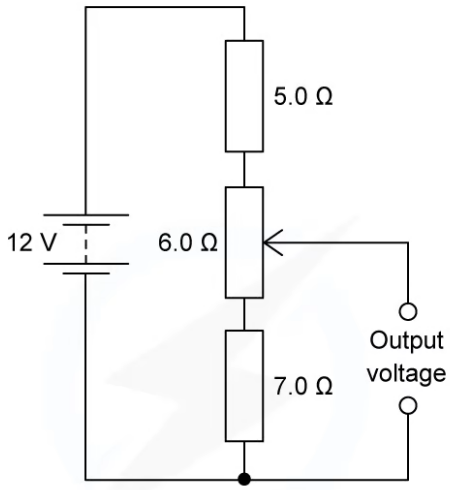
YOUR NOTES

Worked Example

A potential divider circuit consists of fixed resistors of resistance 5.0 Ω and 7.0 Ω connected in series with a 6.0 Ω resistor fitted with a sliding contact. These are connected across a battery of e.m.f 12 V and zero internal resistance, as shown.



What are the maximum and minimum output voltages of this potential divider circuit?

	Maximum voltage / V	Minimum voltage / V
A	8.7	4.7
B	6	0
C	12	6.5
D	12.5	4.7

ANSWER: A

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THE POTENTIAL DIFFERENCE AT THE TOP OF THE CIRCUIT (+ TERMINAL) IS 12V. AT THE BOTTOM OF THE CIRCUIT (– TERMINAL) IS 0 V.

POTENTIAL DIVIDER EQUATION FOR 3 RESISTORS

$$V_{out} = V_{in} \times \left(\frac{R_1 + R_2}{R_1 + R_2 + R_3} \right)$$

MAXIMUM OUTPUT VOLTAGE

THE OUTPUT VOLTAGE IS MAXIMUM AT THE MAX VALUE OF THE VARIABLE RESISTOR = 6.0 Ω

$$\text{MAXIMUM OUTPUT VOLTAGE} = 12.0 \times \left(\frac{6.0 + 7.0}{5.0 + 6.0 + 7.0} \right) = 8.7 \text{ V}$$

MINIMUM OUTPUT VOLTAGE

THE OUTPUT VOLTAGE IS MINIMUM AT THE MIN VALUE OF THE VARIABLE RESISTOR = 0 Ω

$$\text{MINIMUM OUTPUT VOLTAGE} = 12.0 \times \left(\frac{7.0}{5.0 + 6.0 + 7.0} \right) = 4.7 \text{ V} = \text{row A}$$

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YOUR NOTES

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YOUR NOTES

The Galvanometer

- A galvanometer is a type of sensitive ammeter used to detect electric current
- It is used in a potentiometer to measure e.m.f between two points in a circuit
- The circuit symbol is recognised by an arrow in a circle:

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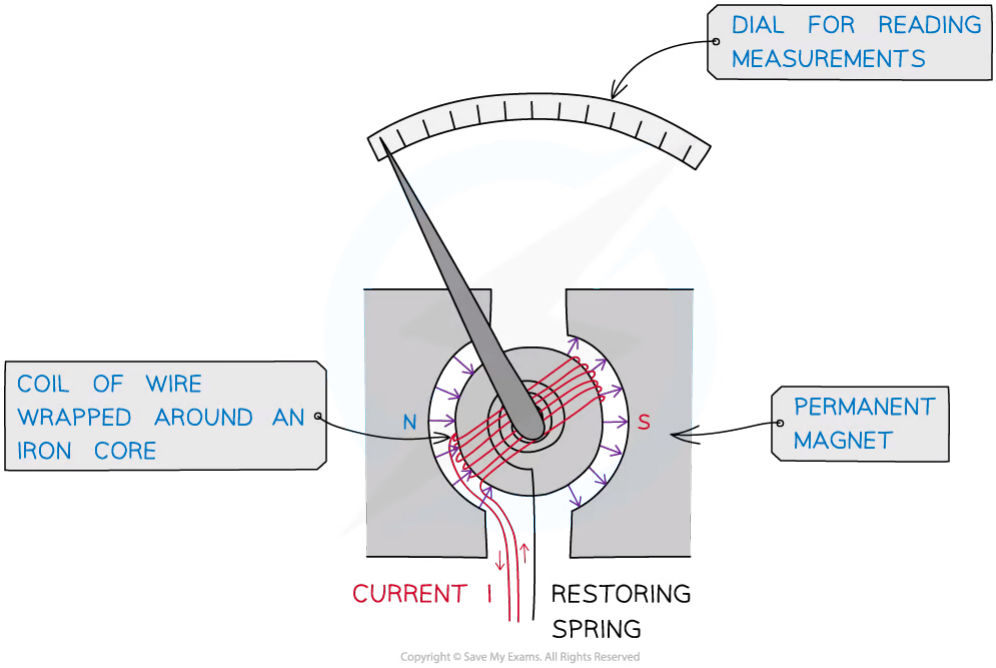
Galvanometer circuit symbol

- A galvanometer is made from a coil of wire wrapped around an iron core that rotates inside a magnetic field:



The galvanometer

- The arrow represents a needle which deflects depending on the amount of current passing through
  - When the arrow is facing directly upwards, there is no current
  - This is called **null** deflection
- Ohm's law tells us that the current through a conductor (wire) is directly proportional to the potential difference through it i.e. **no p.d means no current** flows through the galvanometer
- A galvanometer has p.d of zero when the potential on one side equals the potential on the other side

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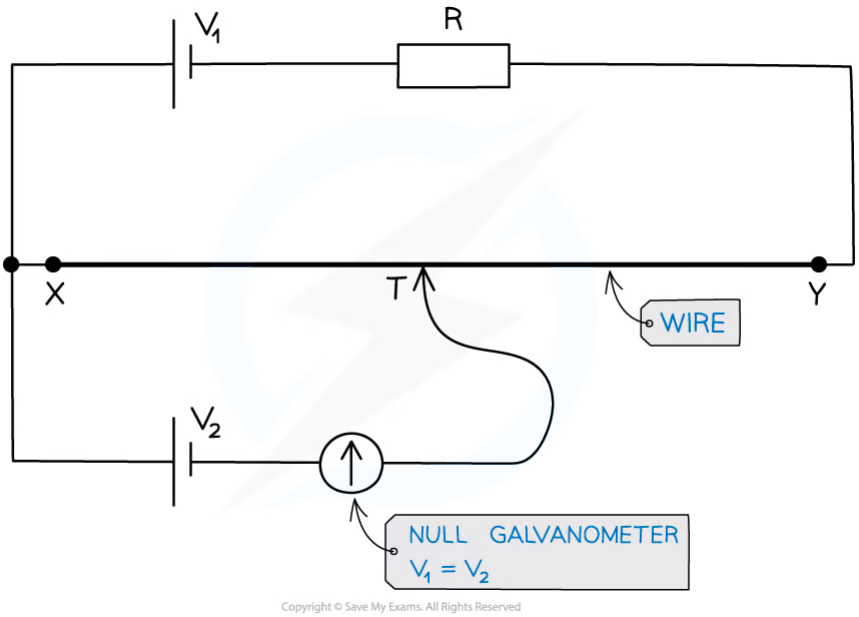
YOUR NOTES

- This is at the **position at which it is connected on the wire (which varies with the sliding contact) gives a p.d equal to the EMF of the cell connected to the galvanometer**
- The cell should be connected such that its potential **opposes** the potential on the wire i.e. the positive terminal of the power supply faces the positive terminal of the cell:



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- When the sliding contact moves along the potentiometer wire, you add or remove resistance from/to the external circuit. This changes the potential drop across X and Y
- Location of the sliding point is adjusted until the galvanometer reads zero. This is until the potential difference equals E_2
- The direction of the two e.m.fs oppose each other and there is no current

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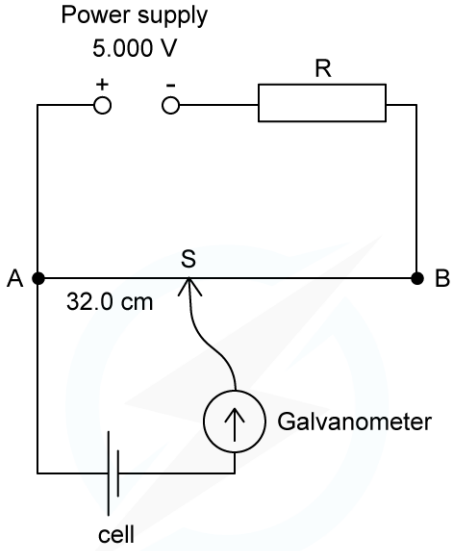
Worked Example

A power supply and a cell are compared using the potentiometer circuit shown.



The e.m.f produced by the cell is measured on the potentiometer. The potentiometer wire AB is 150.0 cm long and has a resistance of 2.4 Ω. The power supply has an e.m.f of 5.000 V and the solar cell has an e.m.f of 6.25 mV.Which resistance R must be used so that the galvanometer reads zero when AS = 32.0 cm?**A.** 735 Ω **B.** 451 Ω **C.** 207 Ω **D.** 401 Ω

ANSWER: D

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YOUR NOTES

STEP 1

IN ORDER FOR THE GALVANOMETER TO READ ZERO, THE e.m.f OF THE CELL MUST BE EQUAL TO THE p.d SUCH THAT THE p.d ACROSS THE GALVANOMETER IS ZERO.

STEP 2

POTENTIAL DIVIDER EQUATION

$$V_{out} = V_{in} \times \left(\frac{R_1}{R_1 + R_2} \right)$$

STEP 3

SUBSTITUTE KNOWN VALUES INTO EQUATION

$V_{in} = 5\ V$ FROM POWER SUPPLY

R_1 = PROPORTION OF RESISTANCE OF THE WIRE AB $= \frac{32}{150} \times 2.4 = 0.21 \times 2.4\ \Omega$

$= 0.504\ \Omega$

R_2 = RESISTANCE OF RESISTOR R = R

$$V_{out} = 5.000 \times \frac{0.504}{R + 2.4}$$

STEP 4

THE GALVANOMETER READS 0 WHEN THE e.m.f OF THE CELL IS 6.25 mV

EQUATING V_{out} TO e.m.f OF THE CELL

$$V_{out} = 5.000 \times \frac{0.504}{R + 2.4} = 6.25 \times 10^{-3}$$

STEP 5

REARRANGE FOR RESISTANCE R

$$R = \frac{5.000 \times 0.504}{6.25 \times 10^{-3}} - 2.4 = 400.8 = 401\ \Omega \text{ (3 s.f.)}$$

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Exam Tip

If you're unsure as to whether the p.d will increase as the contact slider is moved along the wire, remember **p.d is proportional to the length of the wire** (from Ohm's law and the resistivity equation). The longer the length of a wire, the higher the p.d

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